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RF Vacuum Microelectronics

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13. ABSTRACT (Maximum 200 words)

We summarize our third quarter progress towards developing a thin film edge emitter vacuum triode capable of 1 GHz modulation at current emission densities of 10 μA/μm for 1 hour. Considerable progress in the development of a good edge emitter has been achieved this quarter. Current densities of >5μA/μm have been measured and continuous operation of a field emitter diode for >70 hours has been achieved. Design of field emitter triodes were completed this quarter and processing of these triodes has commenced. Atomic force microscopy was used to characterize the emitter surfaces and finite-element modeling of the triode was carried out.

14. SUBJECT TERMS
Vacuum microelectronics, edge emitter, triode, high frequency devices

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R&D Status Report
RF Vacuum Microelectronics
Quarterly Progress Report #3
(4/1/1992 - 6/30/92)

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Effective Date of Contract: September 30, 1991

Contract Expiration Date: March 31, 1993 (Baseline)

Contract Amount: Baseline $1,315,650

Option: $ 772,532

Principal Investigator: Tayo Akinwande 612/887-4481

Program Manager: David K. Arch 612/887-4404

Title of Work: **RF Vacuum Microelectronics**

I. Executive Summary

Program Objective: **Demonstrate an edge emitter based vacuum triode with emission current density of 10 μA/μm at less than 250 V which can be modulated at 1 GHz continuously for 1 hour.**

Key Achievements (this reporting period)

- Demonstrated current densities of 5 μA/μm for diode field emitters.
- Achieved a maximum current emission of 155 mA for a single diode edge emitter. This is a factor of nearly 10x larger than that achieved previously.
- Demonstrated >70 hours of continuous field emission at currents greater than 5 μA for a 48 μm long field emitter.
- Carried out atomic force microscopy measurements on thin film emitter materials to characterize the emitter surface.
- Completed the design of the triode field emitter. Masks have been ordered and the first process run has commenced.
- Carried out thermal FEM analysis on triode emitters which showed that ionic heating from the anode is responsible for the large temperature increases at the emitter.
- Demonstrated high resistivity polysilicon thin films for current limiters in field emission devices.
- Completed four fabrication runs of diode field emitter devices.

A detailed writeup of these achievements can be found in the Third Quarterly Technical Report (4/01/92-6/30/92), RF Vacuum Microelectronics, dated 7-21-92.

II. Milestone Status

	Completion Date	
	Planned	Actual (estimate)
1. Field Emitter Development		
Test Structure Design Complete	12/91	1/92 (complete)
Determine Workable Emitter Structure	3/92	3/92 (complete)
Demonstrate Emission Current of 10 μA/μm	11/92	11/92 (on plan)
Deliver 10 Field Emitting Diodes	12/92	12/92 (on plan)
2. Process Development		
High Resistivity Thin Film Resistor	4/92	9/92
Complete Dielectric Studies	5/92	6/92
Mechanical and Electrical FEM Analysis	5/92	8/92
3. Triode Development		
-Triode Design Complete	4/92	5/92 (complete)
-Demonstrate Reliable/Uniform Current Emission	7/92	9/92
-Demonstrate Modulated/Edge Emitter Triode	8/92	9/92
-Demonstrate 1 GHz Modulation of Triode	2/93	2/93
-Deliver 2 Triodes	3/93	3/93
4. Final Report (Baseline)	4/93	4/93

III. Technical Progress

Efforts during this reporting period focussed on the following:

- Fabrication of thin film emitter diodes
- Extensive testing of field emitter diodes for current emission, emission uniformity, emission current behavior versus control voltage, etc.
- Characterization of thin film dielectrics (sputter and PECVD deposited SiO_2, Si_3N_4, etc.) for use as insulators in diode and triode structures
- Finite element modeling of the thermal characteristics of the thin film edge emitter triode deice
- Design of the edge emitter triode structure
- Characterization of thin film high resistivity polysilicon for use as current-limiting resistors.

Task 1. Field Emitter Development

Four two-terminal device (field emitter diode) fabrication runs were completed this quarter. The objective of these runs were to (i) verify the diode process and masks (run 1 only), (ii) to study the influence of emitter thickness on the performance of the devices, and (iii) to study the influence of emitter material on device performance. The devices from these fabrication runs are presently being extensively tested.

Initial testing of field emitter diodes from the first fabrication run show quite promising results. We have measured diode emitters with current densities of the order of 5 μA/μm. This emission current density is now within a factor of two of the program goal. All indications are that emission is coming from along the edge and not from a single point although we have yet to determine if it is uniform emission. Maximum currents of up to 155 μA have been obtained for some devices, which is almost an order of magnitude larger than previously reported. Finally, we have been able to sustain current emission from some of these diodes for greater than 70 hours continuously at currents greater than 5 μA and at voltages of 180V. All of these devices had TiW thin film edge emitters. Testing is continuing on these devices and devices from the second, third and fourth fabrication runs. Our automated vacuum test station is now fully operational and we are taking device data 24 hours a day.

Task 2 Process Development

Work was carried out this quarter on analysis of our thin film emitter materials using atomic force microscopy; on methods to chemically polish the emitter edge after its definition by lithography and etch; on etch selectivity of emitter materials; on the electrical isolation properties of various dielectrics; and on the characterization of high resistivity polysilicon thin films for current limiters.

We conducted atomic force microscopy (AFM) measurements to determine the surface roughness and the edge roughness of the thin films. Our main objective of the experiment was to determine the intrinsic short range roughness of thin films used in the emitter of our field emission devices and also determine the roughness introduced on the edges by the thin film definition process. Our initial results on a composite surface of silicon substrate, 1.4 μm oxide, 1000 Å of silicon nitride and 200 Å of TiW showed the average height of the surface to be 9.7 Å with a RMS roughness of 27.1 Å. Some difficulty of measurement was seen due to the size of the probe tip used. We plan on using sharper tips in the future. These measurements and analysis will continue.

Etch studies on emitter materials were performed this quarter. Evaluations of TiW, WNx and WSix were made. The results indicate that TiW and WNx etch at a faster rate than WSix. This indicates that it would be possible to form a well-formed edge out of a WSix/TiW or WSix/TiW composite if WSix is the center material. Work in this area will continue next quarter.

We continued our studies from last quarter of various dielectric materials for VME structures. As there will be high electric fields present in the structures, the dielectric films must be of high quality for electric isolation between the emitter, anode and control electrodes. The results of our studies indicate that oxide films (both sputtered and PRCVD oxides) provide the best dielectric isolation between active layers in the diode and triode structures. The oxide films show very low levels of current ($<10^{-7}$ A/cm^2) for fields up to 8×10^{6}V/cm. Annealing experiments show that this dielectric isolation is not improved by high temperature treatments. Our conclusion is that the oxide films (of the order of 5000Å thick) should provide good isolation for the control voltages (<250 volts) needed for the thin film edge emitter devices.

We also examined the use of high resistivity thin film polysilicon for current limiting resistors., We were able to demonstrate good quality 1-2 meg ohm/square 1000Å-3000Å Si films. Devices will be fabricated with this material during the next reporting period.

Task 3 Triode Development

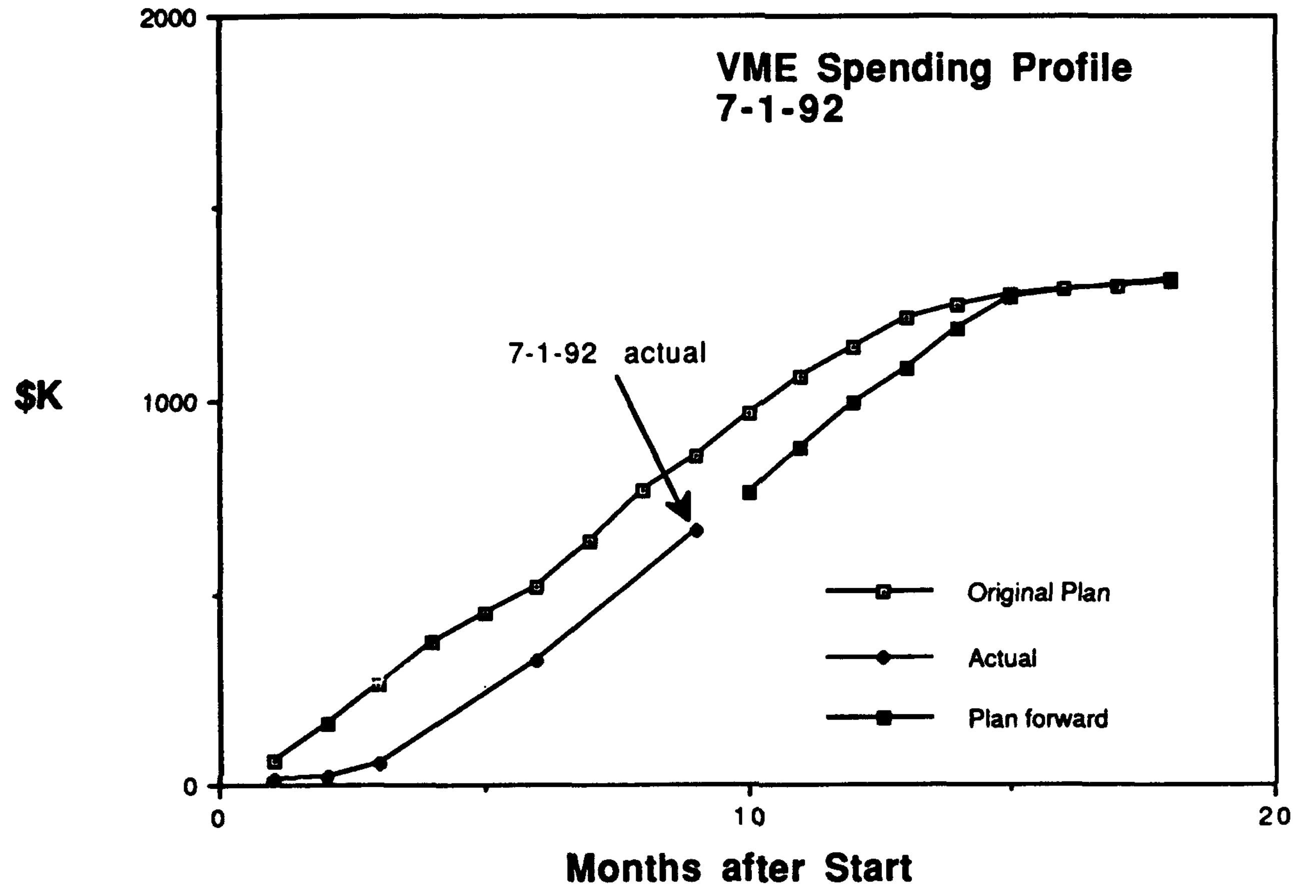
Finite element modeling of the thin film edge emitter triode continued this quarter. Thermal analysis of the triode indicates that ionic heating from ions off the anode are responsible for the large temperature rise of the emitter. These results are somewhat speculative at this point but provide us with a general direction in our triode designs and testing. We completed the triode mask set this quarter. The triode mask set is designed to investigate the benefits of various anode and emitter structures and look at various physical effects including the above mentioned ionic heating. Various emitter configurations, including multiple emitter fingers with and without series resistors and monolithic emitters, with and without series resistors, are included. Different anode configurations, including "zigzag" structures, reduced height anodes and thick, refractory metal anodes were designed.

The mask set has been ordered and we anticipate beginning the first fabrication runs after the Fourth of July weekend.

Plans for Next Reporting Period

- Redesign the field emitter mask set to obtain a diode array with the goal of achieving the 5A cm^{-2} and 5 mA total current objectives.
- Fabricate and test two emitter triode fabrication runs. Demonstrate uniform current emission and modulation of the triode.
- Continue testing of diodes processed in the last quarter.
- Evaluate cermet as an emitter material. Indications are that cermet (such as TaN/Si_3N_4 or $CrSi2/SiO2$) have low work functions which may be practical for field emitter devices.
- Carry out further atomic force microscopy experiments to study the roughness and continuity of the deposited metal emitter films.

IV. Fiscal Status



Expenditures this quarter	$336,771
Total expenditures to date	$660,404
Projected expenditures:	
7/92 - 9/92	$334K
10/92 -12/92	$275K
Total Projected Cost for FY92	$ 995K
Total Projected Cost for Baseline Program	$1,315,650

V. Problem Areas

No main technical barriers or administrative problems are apparent at this point in the program.

VI. Visits and Technical Presentations

- A paper entitled "Thin-film-edge emitter array vacuum transistor" was accepted for the Fifth International Vacuum Microelectronics Conference in Vienna, Austria, July 13-17, 1992. Tayo Akinwande will present the paper. Acknowledgement to DARPA is given in the paper.

- An abstract entitled "Nanometer Thin-film-edge Emitter Devices with High Current Density Characteristics" has been submitted to Dr. Hui at DARPA for approval to submit to the International Electron Devices Meeting (IEDM) scheduled for San Francisco in December.